Laser Based Diagnostics for Measuring H- Beam Parameters

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OUTLINE

• Overview of laser based H⁻ beam diagnostics
• SCL laser wire profile monitor
• HEBT laser emittance scanner
• MEBT laser bunch shape monitor
• Commissioning experience
• Conclusion
Non-invasive Beam Profile Diagnostics at SNS

Ion Source

MEBT

DTL

CCL

SRF, $\beta = 0.61$

SRF, $\beta = 0.81$

2.5 MeV

87 MeV

186 MeV

387 MeV

1 GeV

Ring

Injection

Extraction

HEBT

RTBT

Liquid Hg Target
Non-invasive Beam Profile Diagnostics at SNS

1. MEBT Laser Bunch Shape Monitor
2. SCL Laser Wire Profile Monitor
3. HEBT Laser Emittance Scanner
4. Electron Scanners (WEOCN2)

Mode-lock Laser
Q-Switch Laser
Non-invasive Beam Profile Diagnostics at SNS

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- 2.5 MeV
- 87 MeV
- 186 MeV
- 387 MeV
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MEBT, DTL, CCL

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HEBT Laser Emittance Scanner

RTBT
Photo-ionization – Physics behind Laser Based Ion Beam Diagnostics

Photo-ionization

\[ H^- \xrightarrow{hv} H^0 \]
Laser Wire Profile Monitor

- Laser
- Y-scan
- X-scan
- Deflector
- H\(^0\)
- H\(^-\)
- electron
- Faraday Cup

X-axis: H\(^-\) beam
Layout of the SNS Laser Wire Profile Monitors

- 4 LW from 200 MeV
- 4 LW from 450 MeV
- 1 LW at 1 GeV

Nd:YAG Laser
- 1064 nm
- 10 ns @ 30 Hz
- 1 J

Laser Wire Station (design)
Laser Wire Station (implementation)

Optics

Laser Wire Station (implementation)

Correction magnet  Collection magnet

1-MW H⁻ Profiles Measured by Laser Wire at SCL

1-MW H⁻ Profiles Measured by Laser Wire at SCL

Measurement time window
<table>
<thead>
<tr>
<th>Magnet Setting</th>
<th>Sigma X</th>
<th>Sigma Y</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCL Mag QH32</td>
<td>0.1</td>
<td>2.64</td>
<td>2.49</td>
</tr>
<tr>
<td>SCL Mag QV32</td>
<td>0.1</td>
<td>5.94</td>
<td>2.67</td>
</tr>
<tr>
<td>SCL Mag QH33</td>
<td>0.1</td>
<td>7.13</td>
<td>2.88</td>
</tr>
<tr>
<td>HEBT_Mag QV01</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HEBT_Mag QH02</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Vertical Profile**

- SCL LW32
- HEBT WS1
- HEBT WS2

**Horizontal Profile**

- HEBT WS1
- SCL LW32
- HEBT WS2

---

**Work performed by Y. Zhang and Y. Liu**
Effects of Laser Pulse Energy

![Graph showing the effects of laser pulse energy on various parameters.](image)

<table>
<thead>
<tr>
<th>Laser pulse energy (mJ)</th>
<th>$\sigma_H$ (mm)</th>
<th>$\sigma_V$ (mm)</th>
<th>$C_H$ (mm)</th>
<th>$C_V$ (mm)</th>
<th>$A_H$ (V)</th>
<th>$A_V$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>2.4</td>
<td>3.2</td>
<td>19.8</td>
<td>23.0</td>
<td>0.38</td>
<td>0.36</td>
</tr>
<tr>
<td>150</td>
<td>2.4</td>
<td>3.2</td>
<td>19.8</td>
<td>23.1</td>
<td>0.71</td>
<td>0.62</td>
</tr>
<tr>
<td>225</td>
<td>2.4</td>
<td>3.3</td>
<td>19.8</td>
<td>23.1</td>
<td>0.95</td>
<td>0.92</td>
</tr>
<tr>
<td>300</td>
<td>2.4</td>
<td>3.2</td>
<td>19.8</td>
<td>23.0</td>
<td>1.14</td>
<td>1.18</td>
</tr>
</tbody>
</table>
Effects of Ion Beam Position

\[ \sigma_H, \sigma_V \]

\[ C_H, C_V \]

HEBT Laser Emittance Scanner (design)
HEBT Laser Emittance Scanner (design)

$\phi$50 um Ti wire

1064nm/200mJ laser pulse
HEBT Laser Emittance Scanner (implementation)
Laser Emittance Measurement

Step 1: $H^- \rightarrow H^0 + e^- \text{ with Laser Wire}$

Step 2: $H^0 \rightarrow p^+ + e^- \text{ with Wire Scanner}$

![Graph 1](image1)

![Graph 2](image2)
Emittance Measurement

Measured emittance: ~ 0.2 mm·mrad

Signal-to-noise ratio will be improved through optimization of signal amplification and wire scanner scheme.
Laser Bunch Shape Monitor: a laser probed sampling oscilloscope

Laser pulses

H⁻ pulses

~100 ps
Mode-Locked Ti:Sapphire Laser

Repetition rate: 80.5 MHz (5th sub-harmonic of the accelerator clock)
Laser Interception Site
Preliminary Measurement using Mode-Locked Laser and MCP at 2.5MeV

RMS size: ~ 110 ps


Experiments are ongoing to investigate fiber transmission

- Damage threshold
- Launch efficiency
- Output beam quality
- Pulse jitter
- Pulse width broadening
# Effects of Radiation

All optics related components are enclosed within ¼” thick stainless steel boxes

<table>
<thead>
<tr>
<th>Hardware</th>
<th>Distance from beam line</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation Hardened Laser (Big Sky U1064-HN)</td>
<td>Laser head (~ 1’)</td>
<td>Laser driver was damaged within 1-2 days.</td>
</tr>
<tr>
<td></td>
<td>Driver (&gt;20’)</td>
<td>Not clear about head.</td>
</tr>
<tr>
<td>Optics stepper motors motorized flippers</td>
<td>~ 1’</td>
<td>No damage found</td>
</tr>
<tr>
<td>Picomotor actuators</td>
<td>&gt; 5’</td>
<td>Open-loop (ν8301) is OK. Close-loop (ν8310) encoder was damaged</td>
</tr>
<tr>
<td>Optical power meter heads (Ophir L50(150A))</td>
<td>&gt; 5’</td>
<td>No damage found</td>
</tr>
<tr>
<td>Gigabit Ethernet cameras (Prosilica GE640)</td>
<td>&gt; 5’</td>
<td>1 of 4 was damaged</td>
</tr>
</tbody>
</table>

Laser Beam Pointing Instabilities

Position (200 m from laser)

Laser Power

Time (sec) | Position (mm) | Power (W)
--- | --- | ---
0 | 0 | 0
100 | 20 | 2
200 | 40 | 4
300 | 60 | 6
400 | 80 | 8
500 | 20 | 2
600 | 0 | 0
Laser Beam Position Stabilization with Feedback Control

\[
y(t) = x(t) + g \varepsilon(t - t_d),
\]
\[
\varepsilon(t) = \lambda \varepsilon(t - t_d) + k \delta(t),
\]
\[
\delta(t) = Y_T - y(t).
\]

Feedback off

Feedback on

±1.25 mm @ 250 m

Longitudinal Scan of Beam Train with Laser Wire

1\textsuperscript{st} mini-pulse

Laser-beam interaction location (unit: sub-rev turn, \(\sim\)30 ns)
Profiles at Different Mini-Pulses
Profiles within a Single Mini-Pulse

Summary

- Three different types of laser based diagnostics have been developed at SNS for measuring H\(^-\) beam parameters.
- World-first large scale, operational laser wire system has been implemented at SNS-SCL. Profile measurement has been conducted on 1 MW, neutron production beam.
- Laser emittance scanner has been commissioned at SNS HEBT.
- Laser based bunch shape monitor is being developed at SNS MEBT.
- Laser based ion beam diagnostics at accelerator facilities is reliable and realistic and can provide novel capabilities.
- More laser based diagnostics are expected as a result of applying fast-growing laser technology.